# OPERATIONAL IMPROVEMENTS OF THE ARGONNE ECR SOURCES


R.C. Vondrasek[1], R.H. Scott[1], R.C. Pardo[1], and H. Koivisto[2]

[1]Argonne National Laboratory, Physics Division, 9700 S. Cass Ave, IL 60439, USA
[2]Department of Physics, University of Jyvaskyla, P.O. Box 35, FIN-40351, Jyvaskyla, Finland



**Abstract**

The performance of the recently upgraded ATLAS 10.5 GHz ECR ion source (ECR 1) has continued to improve with a factor of 12 increase in the intensity of high charge state ions ($O^{7+}$, $Ne^{9+}$, $Ni^{16+}$, $Kr^{17+}$) and greater source stability. Use of the sputter technique with a natural nickel sample has produced a $^{58}Ni^{17+}$ beam with an intensity of 16.0 eμA. The solenoid power supplies are presently running at their maximum rated output and replacement of these supplies is planned to further increase the axial magnetic field.

The MIVOC method has been employed at the 14 GHz ECR ion source (ECR 2) to produce a $^{56}Fe^{15+}$ beam with a peak performance of 25.0 eμA. Efficiency into the 15+ charge state has been measured at 0.47%. A high temperature oven was used to produce a $^{50}Ti^{12+}$ beam with an intensity of 6.9 eμA. A $^{238}U^{37+}$ beam with an intensity of 3.0 eμA was produced using the sputter technique. Use of a second frequency has been restored with a 50-100% increase over single frequency operation in the intensities of the medium charge states and a factor of 2 to 5 increase in the higher charge states.


## INTRODUCTION

The increasing demand for high charge state high intensity beams has motivated the improvements to the ECR ion sources at Argonne National Laboratory. The ECR sources now account for 75% of the beams delivered to experiments and this percentage continues to increase along with the variety of beams required by the experimental program, as shown in Figure 1. This has necessitated robust source performance as well as rapid beam changes. In addition, a new program for the production of super-heavy nuclei has begun which requires intense beams of rare isotopes. This has motivated the investigation of the MIVOC method as well as a return to two-frequency heating.

## ECR 1 PERFORMANCE

The ion source ECR 1 was upgraded in October 2000 [1] and the source returned to full operation in 2001. The source was upgraded from a two-stage to a single stage device with a new higher field hexapole (0.84 T at the wall), an aluminum plasma chamber, and new iron yoke. The upgrade has produced a marked increase in the available beam currents for many ion species, as detailed in Table 1, and has greatly simplified and stabilized source operation.

The performance of the source in sputter mode [2] has improved. The peak charge state of $^{58}Ni$ has increased from 13+ to 17+ along with a factor of 25 increase in beam current. An air-lock system is in use to speed sample changes. The time from shutting off one sample, changing to the next, restarting the source, and delivering beam to the linac is typically 30 minutes. The sputter consumption rate is typically 0.80 mg/hr for a 10 eμA beam of $^{58}Ni^{16+}$ but the efficiency remains low at ~0.1%. Despite its low efficiency, the sputter method continues to be preferred for experiments where a moderate beam current is required due to its ease of operation.

The overall source performance continues to improve as new operational modes are reached, and the behavior of the source indicates the need for higher axial magnetic fields. The solenoid coil power supplies are presently running at their maximum rated output of 500 Amps each, producing peak fields of 1.3 kG at injection and 0.87 kG at extraction with corresponding mirror ratios of 4.33 on the injection side and 2.89 on the extraction side. To facilitate an increase in the axial magnetic field, the two existing 500 Amp units will be operated in parallel mode and provide power solely to the injection solenoid. The extraction solenoid will be powered by three 15 kW high-frequency switching supplies capable of supplying a total of 555 Amps. If the need arises, another 15 kW power supply can be added to increase the available current to 740 Amps.

## ECR2 DEVELOPMENT

Development work at ECR 2 has focused on improving beam currents for the super-heavy research program under way at Argonne National Laboratory. A $^{50}Ti$ beam was provided for an experiment designed to produce $^{257}Rf$. The titanium was introduced into the source via a standard high temperature oven [3] which operated at ~1600 °C. To help achieve this operating temperature, the oven was shifted from a radial to an axial position allowing additional heating from the plasma. A beam of $^{50}Ti^{11+}$ produced from the metal (70% enrichment) was delivered on target for a period of 7 days with a maximum intensity of 72 pnA and an average intensity of 50 pnA.

The high operating temperature of the oven was at the thermal limit of the alumina structural elements, and this eventually produced a breakdown of a portion of the alumina body. New oven bodies were constructed of a higher purity alumina (99.5%) with a maximum operating temperature of 1750 °C. The structural elements of these new ovens withstood the high operating temperatures, however, the tungsten/rhenium heating filament was at a sufficiently high temperature to evaporate material onto the alumina surfaces. This surface coating created a second electrical conduction path that initially caused unstable oven operation with the temperature varying +/- 75 °C. After several days of operation enough material was deposited such that the electrical paths were well established. This helped to stabilize the oven operation as well as the temperature. A beam of $^{50}Ti^{12+}$ produced from the metal (95% enrichment) was delivered on target for a period of 5 days with a maximum intensity of 130 pnA and an average intensity of 50 pnA. The material consumption rate was 0.45 mg/hr with an average efficiency of 0.3% into 12+ charge state.

The production of an iron beam has been pursued using the MIVOC method [4]. This technique has produced a peak charge state of $^{56}Fe^{15+}$ with an intensity of 25.0 eμA. The efficiency and beam production of this method is superior to that of the high temperature oven. The ferrocene produced 56% more beam in the 15+ charge state with a corresponding decrease in material consumption from 1.05 to 0.88 mg/hr (for the $^{56}Fe$ isotope) and an increase in efficiency from 0.19 to 0.47%. An attempt was made to introduce the vapor through the hexapole radial slot via a high conductance tube (6.8 $\ell$/s), but this did not result in an increase in efficiency or beam production. Results obtained at other labs [5,6,7] indicate that a reduction in the consumption rate and an increase in the efficiency are obtainable and work continues with this method to find the optimum configuration.

The sputter technique was utilized to produce a $^{238}U^{31+}$ beam with an intensity of 6.0 eμA using single frequency heating and oxygen mixing gas, shown in figure 2. A beam of $^{238}U^{37+}$ at 2.0 eμA was delivered to ATLAS and represented the first time that a uranium beam was accelerated to the coulomb barrier at the ATLAS facility without the need for additional stripping. This resulted in an improvement in the beam quality as well as simplification of the accelerator tune. The beam available for research was 14 pnA at 6.1 MeV/u.

Previously this high charge state could not be achieved with sufficient intensity. This was attributed to an abnormally high plasma chamber pressure [8] depressing the charge state distribution. For the most recent run, the plasma chamber pressure was reduced from 3.0e-7 to 1.7e-7 Torr. This resulted in the peak of the charge state distribution shifting from 25+ to 31+ with an increase in the intensity of the 31+ from <0.50 eμA to 6.0 eμA. Further development work produced 3.0 eμA of 37+ and 21.0 eμA of 28+. This was accomplished by increasing the material flow from the sputter sample into the plasma. Source operation remained stable even with the high influx of neutral material and the small plasma instabilities caused by the sputtering process.

During an accelerator mass spectroscopy (AMS) experiment to detect $^{39}Ar$ in ocean water samples [9], a closed quartz liner was utilized to reduce background contamination produced by $^{39}K$, which is naturally present in the ion source. It was assumed that the source of the potassium was the aluminum plasma chamber wall, and the quartz liner was used to provide a clean surface to the plasma. The liner was baked at 350 °C for several hours before insertion into the ion source and care was taken during handling to not expose it to any potential contaminants. A 5.0 mm hole at the injection end provided for gas inlet and a 10 mm hole for the beam extraction (the extraction electrode diameter is 8.0 mm). The only pumping on the chamber was through the extraction aperture in order to minimize the consumption rate of the sample material and to maximize efficiency. This method was successful with a factor of 10 reduction in the potassium background. The $^{40}Ar$ beam intensity, which was used as a measure of source performance, decreased from 100 eμA to 80 eμA with the use of the liner, but there was no effect on the $^{39}Ar$ count rate.

The use of the liner revealed a problem with the radial magnetic confinement of the plasma provided by the permanent magnet hexapole constructed of six NdFeB bars [10]. During the experiment the source performance degraded and the decision was made to open the source in order to investigate the cause. A 1.0 cm hole in the quartz liner produced by a concentrated plasma loss was discovered. Measurements with a Hall probe revealed a 45% drop in the magnetic field of a 1.0 cm section of the hexapole bar at the corresponding location. The bar was replaced with a spare and the experiment resumed within 7 hours. It was later determined that the bar was originally damaged in 1997 during a cooling water failure. Over the next several years, the weakened state of the bar allowed the plasma to concentrate its loss at the damaged area and locally heat the bar, further lowering the field. A second bar is showing a similar decrease in field strength and will be replaced as well.

## TWO-FREQUENCY HEATING

The use of two frequencies is utilized to improve beam production as well as source stability by providing a second resonance surface for electron heating [11]. ECR 2 originally took advantage of this condition through operation at 10.5 and 14.0 GHz [12] until the unit used to provide the second frequency, a World War II era 10.5 GHz magnetron, failed and no replacement magnetron was available. A traveling wave tube amplifier (TWTA) with a tunable range of 11.0 – 13.0 GHz was recently purchased to replace the failed magnetron. The tunable aspect of the TWTA allows the transmitter to operate as either the primary or secondary frequency for either ion source. The unit is rack mounted and air-cooled permitting ease of movement from one source to the other.

Tests were performed with $^{16}O$, $^{20}Ne$, $^{56}Fe$, $^{86}Kr$, and $^{238}U$ with the results shown in Figure 3. A more detailed analysis of the results is presented elsewhere [13]. The goal of the $^{86}Kr$ test was to produce 15 pμA of $^{86}Kr^{14+}$, the intensity needed for the driver linac of the proposed next generation radioactive isotope accelerator (RIA). This goal was achieved with the production of

210 eμA of $^{86}Kr^{14+}$ from the ion source with 974 W of 14 GHz RF power and 400 W from the TWTA at 10.81 GHz at 14.0 kV extraction with oxygen support gas.

This work supported by US D.O.E. Nuclear Physics Division under contract W-31-109-ENG-38.

**REFERENCES**

[1] D. Moehs *et al*., Rev. Sci. Instrum. **73**, 576 (2002)
[2] R. Harkewicz *et al*., Rev. Sci. Instrum. **66**, 2883 (1995)
[3,8,12] R.C. Vondrasek and R.C. Pardo, *Proceedings of the 14th International Workshop on ECR Ion Sources,* p. 191, CERN, Geneva, Switzerland, May 1999
[4] H. Koivisto *et al*., Nucl. Instrum. Methods Phys. Res. B **94**, 291 (1994)
[5] H. Koivisto *et al*., Rev. Sci. Instrum. **73,** 534 (2002)
[6] T. Nakagawa *et al*., Rev. Sci. Instrum. **69,** 637 (1998)
[7] P. Leherissier *et al*., Rev. Sci. Instrum. **73,** 558 (2002)
[9] W. Kutschera *et al*., Nucl. Instrum. Methods **B92**, 241 (1994)
[10] M. Schlapp *et al*., *Proceedings of the 13th International Workshop on ECR Ion Sources*, College Station, TX, p. 22 (1997)
[11] Z. Q. Xie, C. M. Lyneis, *12th International Workshop on ECR Ion Sources*, Riken, Japan, 1995, p.24
[13] R. Vondrasek *et al, 15th International Workshop on ECR Ion Sources,* Jyvaskyla, Finland, 2002

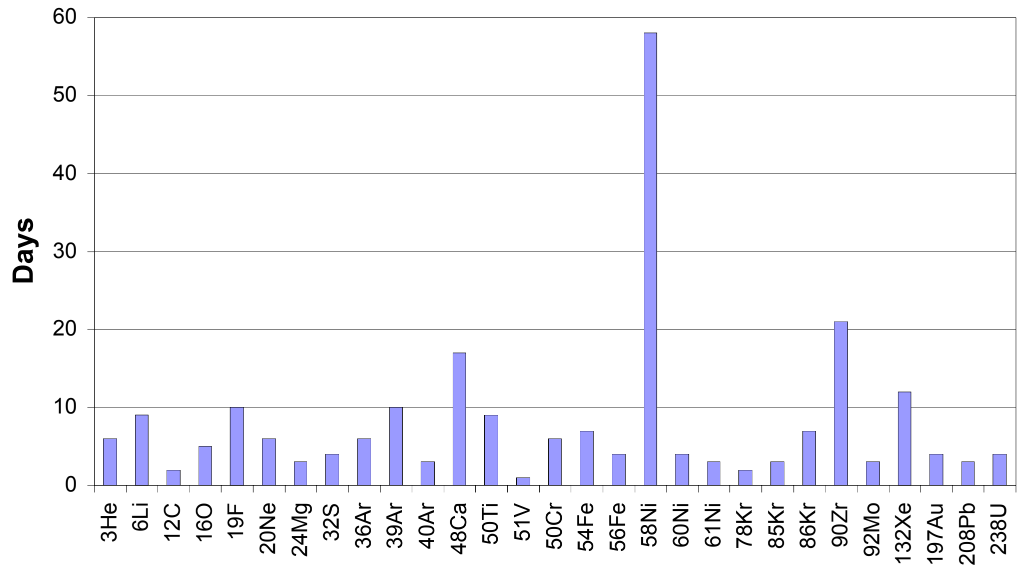


*Figure 1: ATLAS ECR beams delivered to experiments for the calendar year 2001.*

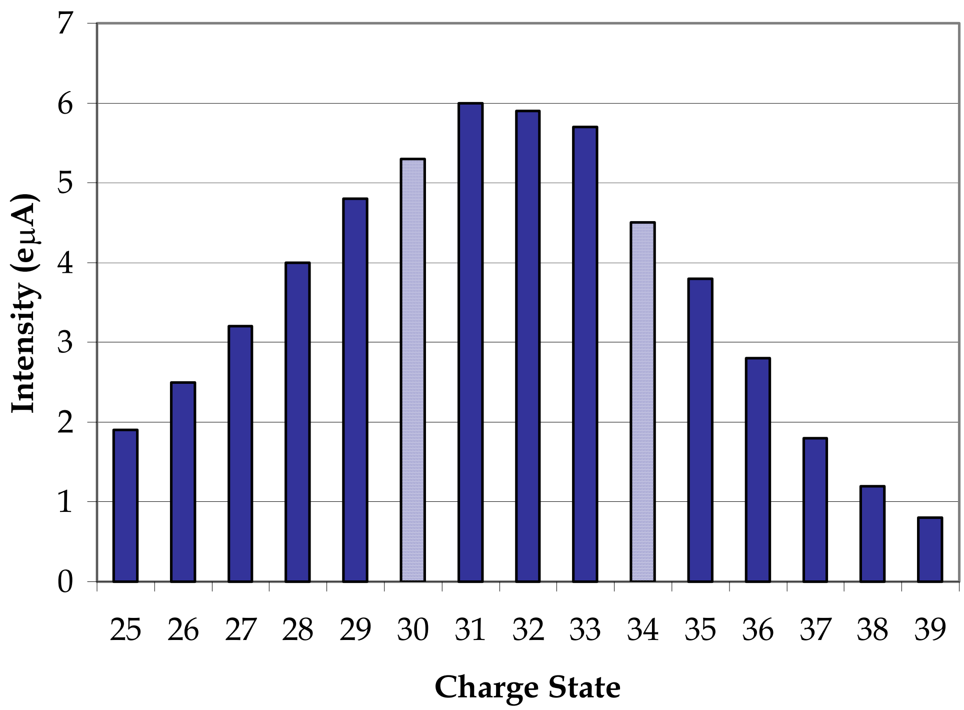


*Figure 2: Uranium beam from ECR 2 using the sputter technique. A depleted uranium metal sample was introduced radially.*

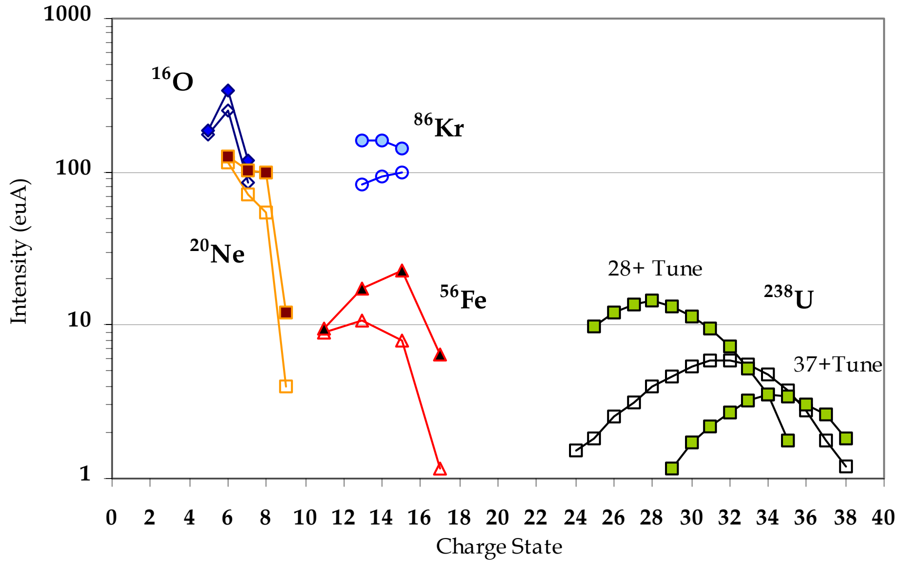


*Figure 3: Increase in beam intensity of various ion species due to two-frequency heating. Filled symbols are with two-frequency heating. Source extraction voltage was 14.0 kV. Helium support gas was used with the Neon. Oxygen support gas was used with the Iron, Krypton, and Uranium beams. No support gas was used for the Oxygen.*

| BEAM SPECIES | PRE-UPGRADE CURRENT (eμA) | POST-UPGRADE CURRENT (eμA) |
|---|---|---|
| 16/5+ | 31 | 225 |
| 16/6+ | 54 | 263 |
| 16/7+ | 4 | 52 |
| 58/15+ | 1.6 | 11 |
| 58/16+ | 1.1 | 15 |
| 58/17+ | 0.6 | 16 |
| 86/13+ | 9.5 | 92 |
| 86/15+ | 16 | 99 |
| 86/17+ | 6.9 | 61 |
| 86/18+ | 2.7 | 38.5 |

*Table 1: Pre and post upgrade performance of ECR 1 for various ion species. All measurements were at 14.0 kV extraction with single frequency heating. No support gas was used with the oxygen, and oxygen support was used with the nickel and krypton (98% enriched).*